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Adaptation to health outcomes of climate change and variability at the city level: An empirical decision support tool

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ABSTRACT

Adaptation to health risk due to climate variability and change at the city level is inadequate, particularly in developing economies. Here, coping strategies with short-term benefits, adopted by the residents contribute significantly to their resilience. Decision on effective adaptation, therefore, requires economic evaluation of the coping and adaptation strategies in practise. In the present paper a novel framework using household health production function (HPF) approach has been developed for evaluation of coping and adaptation strategies to serve as a decision tool for planners. The outcome informs decision makers about the benefits and effectiveness of coping, and shortcomings in the existing adaptation strategies, thus, contributing to stocktaking. The approach has been validated using a case of vector-borne disease of dengue, an important climate-sensitive health impact of climate change. A five step cyclical framework has been proposed which addresses uncertainty by avoiding the need for future projection of health outcomes and scenario building as it can be applied at any point of time in future and considers the current risk only. The strengths and weaknesses of the proposed tool are compared with other similar tools. The decision support tool has applicability for all climate-sensitive health outcomes at the city level.

1. Introduction

Adaptation to climate change is essentially planned and implemented at the local level and is context-specific (Corfee-Morlot, Cochran, Hallegatte, & Teasdale, 2011; Craft & Fisher, 2018; Lambert et al., 2011; Measham et al., 2011; Nalau, Preston, & Maloney, 2015). With increase in recognition of impacts of climate change at the city level, urban adaptation has gained significance among the adaptation planner (Araos, Berrang-Ford et al., 2016; Araos, Austin, Berrang-Ford, & Ford, 2016; Hunt & Watkiss, 2011; Revi et al., 2014; Wilbanks, 2011). At the city level, the risks associated with climate change are unique because of greater population density and diversity, complex built environment and dependence on technological system for survival (Araos, Austin et al., 2016; Harlan & Ruddell, 2011; Hunt & Watkiss, 2011). In 2018, 55 percent of the global population is urban and it is likely to increase to 68 percent by 2050. Nearly 90 percent of the increase in urban population by 2050 will be concentrated in the cities and towns of Asia and Africa (United Nations, 2018). This further adds to the need for adaptation for climate-related risk in cities. Among the risks, climate-sensitive health risks have often received lesser attention in adaptation planning (Austin et al., 2018). Adaptation to health risks which contribute to the resilience and sustainability of the cities remains a challenge for the planners.

Urban residents are mainly vulnerable to the health impacts of increased incidence of heat waves and heat-stress, water-borne diseases and vector-borne diseases (VBDs) like dengue and malaria (Hunt & Watkiss, 2011; Smith et al., 2014). It has been projected that even a warming at 1.5 °C, the number of megacities experiencing heat stress would double, exposing additional 350 million residents by 2050. The deadly heat wave conditions of 2015 in cities like Kolkata (India) would become annual event in case of warming up to 2 °C (Hoegh-Guldberg et al., 2018). Over the last five decades, there has been a 30 fold increase in dengue which is predominantly an urban vector borne disease (Bhatt et al., 2013; Brady et al., 2012; Ebi & Nealon, 2016; Guo et al., 2017; World Health Organization, 2019) with an estimated economic burden of US$ 950 million or around US$ 1.5 per capita (Shepard, Halasa, Undurraga, & Stanaway, 2015). Reducing these risks through interventions or adaptation measures in cities, therefore becomes necessary to increase the adaptive capacity of the urban residents (Carter et al., 2014; Grimmond, 2007; Rosenzweig et al., 2011). Also, such adaptation contributes to achieving the sustainable development goals (SDGs) relating to health, resilient and sustainable cities and climate change impacts (SDG 3, 11 &13) (Sustainable Development Solutions Network, 2018).

At the city level, there have been very few adaptation initiatives for health risk (Araos, Austin et al., 2016; Araos, Berrang-Ford et al., 2016).

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Most of the initiatives are restricted to cities in developed economies and the focus has been mainly on heat related impacts with very limited efforts towards adaptation strategies for other climate-sensitive health outcomes like VBDs (Araos, Austin et al., 2016; Confalonieri et al., 2007; Hunt & Watkiss, 2011; Revi et al., 2014). Also, published evidence of the effectiveness of health adaptation is very limited, particularly in developing countries (Ebi & del Barrio, 2017). The effectiveness of adaptation would depend on selection of appropriate measures, effective over longer-term. Thus to have an effective health adaptation at the city level, it is essential to have an efficient decision tool to support policy making which is capable of providing information on economic viability and empirical evidence on the effectiveness of the adaptation measures. The aim of this paper is to come up with such decision support tool for health adaptation.

The health impacts of climate change are experienced at the individual, household and community level. Hence, the local government at the city level serves as the first line of defence and are responsible for the public health preparedness and response (Sheehan, Fox, Kaye, & Resnick, 2017). The local government are well aware about the needs of local population and therefore, can be more proactive than national governments in addressing the public health requirements of the urban population (Frumkin, Hess, Luber, Maililay, & McGeehin, 2008; Maibach et al., 2008; Barata et al., 2011; Sheehan et al., 2017). National government mainly provides broad policy directions, while local government or municipalities plan and implement adaptation strategies (Araos, Austin et al., 2016; Austin et al., 2018). An empirical decision support tool for health adaptation at the city level based on bottom-up approach after considering the contribution of coping strategies by residents in building adaptive capacity has been proposed in this paper. The tool has been developed to support a well informed decision on health adaptation by the local government. The tool serves the purpose of evaluating the effectiveness of the health adaptation already undertaken at the city level, thus contributing to the stocktaking requirement under Article 7, paragraph 14 of the Paris Agreement (Craft & Fisher, 2018; Tompkins, Vincent, Nicholls, & Suckall, 2018).

The proposed decision framework for the first time uses health production function (HPF) as a decision tool for health adaptation at the city level in an 'adaptation pathway approach' and can be used at any point of time. It provides information on cost, benefits and effectiveness of adaptation strategies inclusive of coping strategies and identifies adaptation deficit. Further, HPF can efficiently evaluate health adaptation measures that have been identified as good practices. Based on the outcome of some of the pilot projects, adaptation measures like early warning and response systems for climate-sensitive health outcomes, capacity building, awareness, disease surveillance, hazard mapping and alert communication systems have been identified as good practices for health adaptation (Ebi & del Barrio, 2017). Evaluation of these measures essentially requires non-market valuation which can be effectively carried out with HPF approach. In addition to supporting decision by local government, it also fulfils one of the good adaptation criteria by informing the sub-national and national government in federal system of governance about the exact requirements of different cities to develop adaptive capacity to health risks. Hence, allowing them to make policy decision to support planning and implementation of health adaptation by local government at city level.

Decision support tool specifically for health adaptation has been developed by WHO-European centre (WHO Regional Office for Europe, 2013) which works essentially in a top-down manner providing the benefits of health adaptation by health ministry at the national and subnational level. There is hardly any published evidence of use of this tool, particularly at the city level. The tool uses cost-benefit analysis (CBA) for decision making. CBA is one of the most commonly used decision support tool for evaluation of adaptation, but has a very limited coverage in case of health adaptation (Chambwera et al., 2014; Watkiss, 2015). It fails to serve as an appropriate tool for evaluation of good practises for health adaptation as valuation of non-market costs and benefits is a major limitation for CBA due to heterogeneity in preferences (Chambwera et al., 2014; Watkiss, Hunt, Blyth, & Dyszynski, 2015). Unlike the decision framework with HPF approach, the tool completely ignores the important contribution of coping strategies in decision making for effective adaptation measures by the local government (Revi et al., 2014; Sahay, 2018a). Failure to incorporate non-market costs and benefits and contribution of coping strategies would result in underestimation of costs, benefits and effectiveness of the health adaptation.

There are studies which have estimated the cost of planned adaptation for future health impacts at the regional level for diarrhoeal disease, malnutrition and malaria (Ebi, 2008; Markandya & Chiabai, 2009; The World Bank, 2010; UNFCCC, 2007) and at the national level for heat related health effects (Barreca, 2012; Barreca, Clay, Deschênes, Greenstone, & Shapiro, 2015; Deschenes & Greenstone, 2011). Studies analysing the benefits are extremely limited (Agrawala & Fankhauser, 2008; Chambwera et al., 2014). The tools used in these studies applied top-down approach to estimate the cost or benefit of adaptation which limits their use for good practices for health adaptation. In addition to CBA, there are other tools like cost-effectiveness (CEA) and multi-criteria analysis (MCA) which are used in different decision making frameworks like iterative risk management (IRM) and robust decision making (RDM). These tools can be used for economic analysis of health adaptation, though each has their own strength and weaknesses with almost no evidence of their use for health adaptation (for details of these tools see Watkiss et al., 2015).

Keeping in view the merits and demerits of these tools and a very limited evidence of their use in making decision on the health adaptation measures, this study proposes an empirical framework based on household health production function (HPF) approach which is then used as decision support tool in a cyclical framework. The decision tool has been developed and validated using a case of dengue, one of the most important climate-sensitive VBDs with prevalence in cities across the tropics, particularly in developing countries (see supplementary material 1 for relation between climate change, dengue risk and adaptation measures). The decision framework has been designed in a way such that it addresses the major concerns related to uncertainty. The advantage of using the framework developed in this paper over other decision framework has been highlighted. The paper is organized as following – Section 2 presents the two stage methodology used in this paper. The results of the two stages are presented in Section 3 which includes the review of literature with the subsequent development of empirical evaluation framework and the cyclical framework. The empirical evaluation framework is used as decision support tool for health adaptation in the cyclical framework. Finally, a section on discussion on the comparative advantage of the proposed framework over the decision making framework of IRM and RDM has been presented.

2. Methodology

The economic evaluation of interventions serves as an important decision support tool for policy makers. Such evaluation of the coping strategies at the city level provides information to the decision makers about the cost, benefits and effectiveness of the strategies. It allows for the assessment of the contribution of coping strategies to urban resilience and identifies the adaptation gap between the existing strategies already in practise and the additional strategies required to build long term resilience to health risk (Sahay, 2018a). A two stage research has been carried out in this paper to develop a decision support tool for health adaptation, based on economic evaluation. In Stage 1 an empirical evaluation framework for economic evaluation of coping strategies has been developed. Using this framework a cyclical decision support framework for health adaptation has been developed in Stage 2. Fig. 1 provides the methodological framework of the 2 stage research carried out for this paper.

To come up with empirical evaluation framework for economic

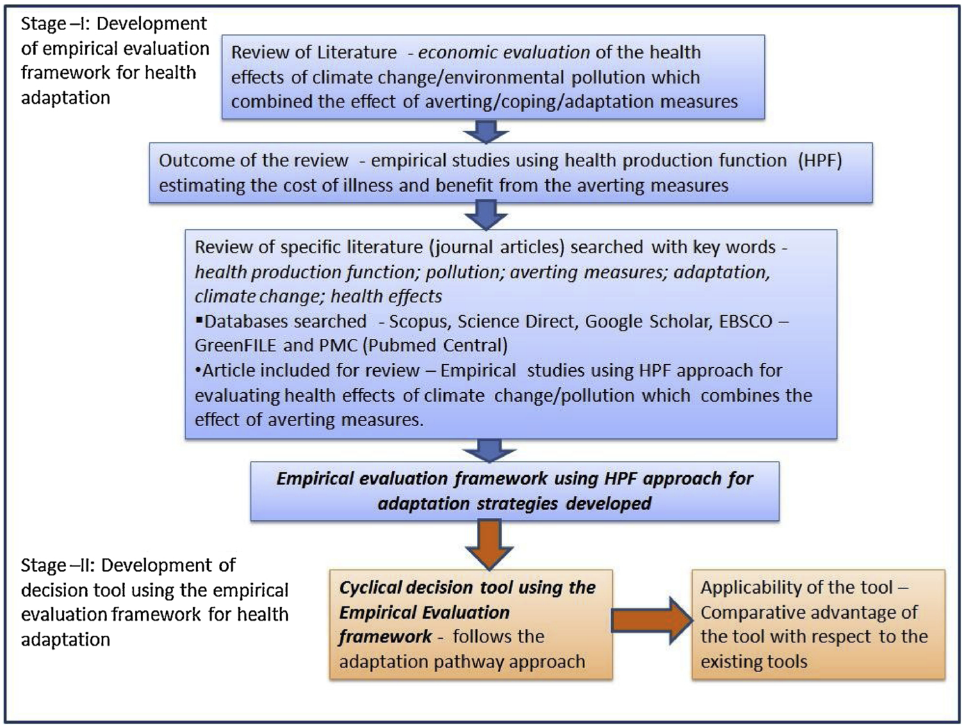

Fig. 1. Methodological framework used for developing the decision tool.

evaluation of coping strategies, review of literature was carried out in Stage 1 of the research for this paper. Initially, literature focusing on economic evaluation of the health effects of climate change and environmental pollution which also combined the effect of averting measures or coping/adaptation measures was reviewed. As economic evaluation studies combining climate change, health effects and coping or adaptation measures are very few, the search for literature was extended to include studies on environmental health effects and averting measures. Initial search of the prominent databases predominantly yielded empirical studies which have used health production function (HPF) for estimating the cost of illness and benefit from the averting measures. Hence, the search criteria was narrowed down to look for empirical studies which have analysed the effect of averting measures on the health impacts of climate change or environmental pollution using HPF approach at the local level (urban as well as rural areas) which includes sub-national areas - counties, states, districts, watersheds and cities. Also, it was not restricted to any specific type of health effects.

The literature search was restricted to journal articles published during the period 1985 – 2018. The key words used for the searches were health production function; pollution; averting measures; adaptation, climate change and health effects. The databases researched include Scopus, Science Direct, Google Scholar, EBSCO – GreenFILE and PMC (Pubmed Central). The empirical studies which exclusively evaluated the health effects of climate change or environmental pollution after combining the effect of averting measures using the HPF approach were selected for review for this study. Outcome of the review is used as the basis for development of the empirical evaluation framework. In stage 2, the HPF based empirical evaluation framework developed is stage 1 is used to come up with a cyclical framework as a decision support tool for health adaptation. The HPF based decision framework has been validated using the recent study by Sahay (2018a) which carried out an economic evaluation of coping strategies for climate sensitive health effect of dengue in city of Delhi, India. Finally, a comparative assessment of the proposed decision framework with the commonly used decision framework of IRM and RDM has been carried out.

3. Results

3.1. Empirical evaluation framework for coping and adaptation strategies

Most of the initial studies on evaluation of adaptation are restricted to theoretical approaches and provide only the methodological framework for assessment of health impact and formulation of adaptation strategies. For example, Ebi, Kovats, and Menne, (2006) proposed a stepwise methodological framework for assessment of vulnerability and adaptation measures at the national level. The steps include determining the scope; description of the current disease burden; past trends and its association with climate variability; identification and description of the current adaptation strategies and policy measures; and estimation of the future potential health impact using climate and socio-economic scenarios. An additional step to these has been suggested by Ebi and Prats (2015) which requires monitoring, reporting, reviewing and updating of the adaptation strategies.

As for the empirical research, till date most of them have focused mainly on the adaptation measures for the heat related health impacts of climate change. The economic literature on adaptation for other health effects such as vector-borne disease of dengue is relatively sparse (Beatty et al., 2011; Sahay, 2018a). Even for heat related health effects, economic literature with empirical research on impact of ambient temperature on health and possible adaptation measures are very limited (Deschenes, 2014). Studies carried out so far have mostly analysed private adaptation (coping strategies) measures using the econometric tools for panel and time series regressions. Adaptation measures used in such analyses includes residential energy consumption for cooling and heating, and access to health care (Barreca, 2012; Barreca et al., 2015; Deschenes & Greenstone, 2011), outdoor time use (Graff-Zivin & Neidell, 2010), geographical mobility and air-conditioning (Deschenes & Moretti, 2009) and early warning system (Benmarhnia et al., 2016; Ebi, Teisberg, Kalkstein, Robinson, & Weiher, 2004).

The conceptual framework for the estimation of health-related welfare impact of temperature change based on the Becker-Grossman style 1-period model of health production, developed by Deschenes and Greenstone (2011) is one of the major advancement in the economic

evaluation of health adaptation. They derive a practical expression for willingness to pay/accept (WTP/WTA) for increase in temperature. The model has been discussed in detail in Graff Zivin and Neidell (2013) and Deschenes (2014). It has been used for analysing the benefits of adaptation to heat related health effects by Deschenes and Greenstone (2011) and Barreca (2012), climate-dependent infectious and parasitic diseases by Amuakwa-Mensah, Marbuah, and Mubanga, (2017) and vector-borne disease of dengue by Sahay (2018a). The result of the searches revealed only these four studies indicating very limited application of health production function in health adaptation studies. However, several models based on the original model of health production function given by Grossman, 1972 have been developed and widely used to estimate welfare impact of reduction in environmental pollution and defensive behaviour[1] .

The health production function has been used for estimating the health benefits due to averting behaviour for reduction in health damage caused by air pollutants (Bresnahan, Dickie, & Gerking, 1997; Deschênes, Greenstone, & Shapiro, 2017; Dickie, 2005; Gerking & Stanley, 1986; Joyce, Grossman, & Goldman, 1989; Mansfield, Johnson, & Van Houtven, 2006; Martini & Tiezzi, 2014; Moretti & Neidell, 2011; Neidell, 2009; Richardson, Champ, & Loomis, 2012), water contamination (Aziz, Aziz, & Boyle, 2014; Aziz, Boyle, & Crocker, 2015; Dasgupta, 2004; Jessoe, 2013; Mokondoko, Manson, & Pérez-Maqueo, 2016; Pattanayak, Yang, Whittington, & Bal Kumar, 2005; Roy, 2008; Sayal et al., 2016) and exposure to pesticides (Bakhsh et al., 2016). Table 1 summarizes the review of empirical studies based on health production function carried out during the recent period (2000–2018). There were only three studies (Bresnahan et al., 1997; Gerking & Stanley, 1986; Joyce et al., 1989) published during 1985–2000 which matched the selection criteria. All the three evaluated the health benefit of averting measures for reduction in health damage due to air pollution in different parts of USA. Hence, only the recent studies from 2000 to 2018 were considered for review. Studies on adaptation to climate-sensitive health risk and studies on averting measures for health risk due to environmental pollution have been presented separately.

Empirical approach used in literature finds the presence of endogenous regressor or endogeneity as one of the common problem in estimation of health production function as it is mostly based on observational data (Gerking & Stanley, 1986; Joyce et al., 1989; Alberini, Eskeland, Krupnick, & McGranahan, 1996; Bresnahan et al., 1997; Dasgupta, 2004; Dickie, 2005; Moretti & Neidell, 2011; Richardson et al., 2012; Jessoe, 2013; Aziz et al., 2015; Amuakwa-Mensah et al., 2017; Sahay, 2018a). The simultaneity arises due to omitted variables or non-zero correlation between the regressor and the outcome and the error term. The variable for coping or averting measures is codetermined with the dependent variable leading to inconsistent and biased estimation due to endogeneity. The coping strategies are the choice of the respondent and thus they are not exogenous.

Different empirical approaches have been used to deal with the issue of endogeneity in estimation of health production function. The commonly used approaches include two-staged least square (2SLS) estimation using instrumental variables (IV) (Jessoe, 2013; Moretti & Neidell, 2011), two-staged residual inclusion (2SRI) using IV (Richardson et al., 2012; Sahay, 2018a) and instrument variable transformation (IV-T) approach through generalized method-of-moment (GMM) estimators (Dickie, 2005). Instrumental variables are used to formalize the relationship between the endogenous regressors and the omitted variables that influence the dependent variable. They are sufficiently correlated with endogenous variable but uncorrelated with the error term. Further, approaches such as one-step system generalised method of moment (GMM) estimation technique (Amuakwa-Mensah et al., 2017); three-staged least square estimation (Roy, 2008) and bivariate probit regression (Dasgupta, 2004) have also been used in this context.

The other prominent issue associated with the estimation is that of ‘count data’ as the dependent variable, usually the ‘number of days ill due to the disease’ is non-negative integer or count data, suggesting a non-normal distribution. Count data usually have Poisson distribution, where the conditional mean equals conditional variance and therefore calls for the use of count data model (Gerking & Stanley, 1986). Studies using HPF approach have addressed the issue by using appropriate econometric tools such as negative binomial regression (Gerking & Stanley, 1986; Richardson et al., 2012; Sahay, 2018a). While some of the studies have avoided this issue by using binary dependent variable for the estimation of probit model (Martini & Tiezzi, 2014; Sayal et al., 2016). The other approaches used in literature include estimation of fixed effect panel regression (Barreca, 2012; Deschenes & Greenstone, 2011), linear regression (Mansfield et al., 2006) and differences-in-differences-in-differences (DDD) estimator (Deschênes et al., 2017).

The review of these studies serves as the basis for the development of an empirical approach for the evaluation of adaptation strategies for climate-sensitive health outcomes. Estimating household health production function using the averting behaviour method can be used for the evaluation of the averting or coping strategies for the climate-sensitive health risk at the city level. Climate change is manifested as change in weather patterns at the city level. The health risk due to change in weather patterns can be used as an exogenous input in the health production function. Following Jessoe (2013) which uses this approach to evaluate the effect of interventions (crowding out) on the private averting measures, it can be used for monitoring and evaluation of the adaptation measures by the local government.

Based on the lacunae in literature with respect to the empirical studies for economic evaluation of health adaptation, this study proposes an empirical evaluation framework for economic evaluation of coping strategies at the city level for climate-sensitive health outcomes such as heat related morbidity and mortality, vector-borne diseases and water-borne diseases. The framework which serves as decision making tool for the policy makers for such climate-sensitive health outcomes has been elaborated using the case of a vector-borne disease of dengue (Fig. 2). The first step involves assessment of the current risk of dengue associated to variations in weather pattern. The climates sensitive health outcomes or the health effects of environmental pollution have been treated as exogenous input in HPF approach (see Table 1 for the health effects examined in literature using HPF approach). There are several studies determining relationship between climate variability, weather and dengue occurrence (Morin, Comrie, & Ernst, 2013; Naish et al., 2014; Sahay, 2018b) (see supplementary material 1). These studies use different methodologies for determining the association between weather patterns and dengue occurrence. Though these studies provide strong evidence of the effect of climatic variables on dengue incidence, complexity associated with modelling and not taking into account of non-climatic confounders such as demographic trends, socio-economic drivers, effects of interventions and human behaviour in model makes them less accurate (Morin et al., 2013). These studies, however, help in identifying the basic pattern and current risk which can be used in this framework.

The second step involves assessment of coping strategies adopted by private actors in response to the risk. The economic evaluation of the coping strategies is carried out using HPF approach. The disease risk associated with the weather patterns which was determined in the first step is used as an exogenous input in the health production function equation. The estimated willingness to pay gives the benefits of the coping strategies. The outcome of the evaluation provides information

[1] Defensive actions comprises of averting and mitigating actions. Actions which reduce the chance of exposure to pollutants which cause negative health outcome like staying indoors, using air cleaner, using AC or mosquitoe repellent are referred to as averting actions. Actions taken after experiencing the health outcome in an effort to mitigate its negative effects, such as going to the doctor or taking medications are referred as mitigating actions. Only averting action was considered for this review.

Table 1
Empirical evidence of economic evaluation of coping/adaptation and averting measures for health risk using health production function (HPF) approach.

Authors	Study Location	Health effects	Averting measures (coping measures)	Methodology	Benefits with averting (coping)/Adaptation measures.
Evaluation of coping or adaptation measures for climate-sensitive health outcomes					
Deschenes and Greenstone (2011)	U.S.A (all counties)	Impact of Temperature on annual mortality over the period (1968–2002)	Residential energy consumption (cooling and heating)	Conceptual framework is derived from Becker-Grossman style 1-period model of health production. Panel fixed effect regression was used for the estimation of mortality and energy consumption.	The total loss in life year and increase in energy consumption are valued to be approximately $1,032,000 per life-year and $863.3 billion per quad in 2099. The cost is overstated as in the long run in addition to energy consumption individuals may adopt wide set of adaptation measures.
Barreca (2012)	U.S.A (373 counties only)	Impact of Humidity and Temperature on monthly mortality over the period (1973–2002)	Residential energy consumption (cooling and heating)	Conceptual framework and Empirical model same as Deschenes and Greenstone (2011). Models also include measure of humidity.	Health-related savings of climate change (in terms of mortality and energy consumption) is $58 billion dollars per year. Using the uncorrected Hadley CM3 predictions, the welfare cost totals $142 billion dollars per year by the end of the 20th century.
Amuakwa-Mensah et al. (2017)	Sweden – 21 Swedish counties	Climate-Dependent infectious and parasitic diseases	Education and number of health personals through increased awareness and per-capita income – beyond certain threshold by increasing public health resources like vaccinations.	Theoretical framework follows the health production function model provided in Graff Zivin and Neidell (2013) which relates climate variability to health effects. Panel regressions using fully modified ordinary least squares (FMOLS) and one-step system generalised method of moment (GMM) estimation technique has been used static and dynamic models respectively.	Monetary benefit not estimated. Education and the number of health personnel have negative effect on the number of patients, while a non-linear – inverted “U” shape relationship was observed between income and the number of patients.
Sahay (2018a)	Delhi, India	Dengue incidence due to climatic variability	Use of mosquitoe repellent both during day as well as night	Theoretical framework based on HPF approach following Deschenes and Greenstone (2011). Negative binomial regression and probit regression has been used to estimate the main and reduced form equation for the coping strategies respectively. Two-staged residual inclusion (2SRI) framework used to deal with endogeneity.	Households WTP or the benefit from the decrease in disease incidence due to adoption of coping strategies comes out to be US$ 65 per household per year.
Evaluation of averting measures for health effects of environmental pollution					
Dasgupta (2004)	Delhi, India	Water-borne disease – Diarrhoeal disease	Water purification	HPF approach used. Bivariate probit regression used for estimating the simultaneous equation.	The annual cost of illness estimated as INR 1094.31 per household and for the city as INR 164.96 million. This cost can be used as WTA for reduction in health damage for the affected household.
Dickie (2005).	USA (Survey data from Child Development Supplement to the Panel Study of Income Dynamics (PSID) carried across the country)	Number of days of acute illness in children	Parental resource allocations on children's health	Health production model of family decision making. The equations estimated using instrument variable transformation (IV-T) approach by implementing generalized method-of-moment (GMM) estimator.	WTP ranged from of $100 to $150 for avoiding one school day loss.

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Table 1 (*continued*)

Authors	Study Location	Health effects	Averting measures (coping measures)	Methodology	Benefits with averting (coping)/Adaptation measures.
Pattanayak et al. (2005)	Kathmandu, Nepal	Health risk due to poor-quality and insufficient water supply	Collecting water from public taps; purchasing it from vendors and neighbours; investing in tube wells, storage tanks, and filtration systems; and boiling water before drinking or cooking.	Conceptual framework based on household production function for understanding coping costs or averting expenditures. A robust and clustered Regression Model of Coping Costs has been estimated. Contingent valuation (CV) method was used to estimate WTP	The estimated coping costs per household on an average was US$ 2.94 per month or about 1% of monthly income and was significantly lower than estimates of WTP for improved services. Benefits can be attributed to coping measures in case coping costs exceed the supply cost of expanding water the network.
Mansfield et al. (2006)	Across the country in USA (Series of eight surveys in ozone season with a common set of households)	Effect of exposure to air pollution – high ozone levels	Reducing outdoor time	Theoretical models that relate health to utility – basic model of health and pollution. Linear regression models used for estimating parameters explaining heterogeneity in taste of at individual level.	WTP range from $20 to $200, Marginal value for a 1-day reduction in restricted outdoor time was estimated as $35.
Roy (2008)	Arsenic-affected area in the state of West Bengal, India	Effect of arsenic contamination in groundwater	Time spent for collecting arsenic free water	Household HPF approach. System of three simultaneous equations for the three endogenous variables – sick days, medical expenditure, and averting expenditure are estimated.	The benefit for each household for reduction in arsenic concentration to the safe limit of 50 μg/l was calculated to be INR. 297 per month
Neidell (2009)	Southern California, USA	Health effects of Ozone represented by asthma hospitalization	Issuing pollutant standard index (PSI) and smog alert a day before which allows child and elderly to stay indoor and others to avoid rigorous outdoor activities.	Conceptual framework based on health production function. Regression discontinuity design has been used to estimate effect of smog alerts on daily attendance and time series regression has been used to estimate the effect of ozone on children and elderly on including alert in the model.	Alert has negative effect on hospitalization for children and elderly. For decrease in ozone concentration by 0.01 ppm, alerts about pollution considerably increases savings from $157,727 to $417, 717 per smog alert season, a difference of $260,000.
Moretti & Neidell (2011)	Los Angeles, USA	Short -run effect of ozone on health/Ozone related hospitalization	Issuing air quality forecast or smog alert by noon the day before.	Conceptual framework based on health production function. The equations are estimated using 2SLS with instrument variable method to derive cost of illness and cost of averting behaviour. Boat traffic at the ports of Los Angeles has been used as an instrumental variable. Variable for ozone concentration is considered as endogenous variable.	Cost of ozone related health effects come out to be $44 million per year using instrument variable estimates and as low as $11.1 million per year on using OLS. Cost of avoidance behaviour ranges from $11.1 to $33.4 million per year
Richardson et al. (2012).	California's Station fire	Health damages from smoke released due to wild fire	Home air cleaner	Health production function with averting behaviour used. The main equation estimated using count data regression approach (negative binomial regression), while the reduced form equation estimated using Probit.	WTP per exposed person for avoidance of one symptom day came out to be $84.42. The average cost of illness per exposed person per day was estimated to be $9.50.

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Table 1 (*continued*)

Authors	Study Location	Health effects	Averting measures (coping measures)	Methodology	Benefits with averting (coping)/Adaptation measures.
Jessoe (2013)	1307 villages in 5 states of rural India – Uttar Pradesh, Madhya Pradesh, Maharashtra, Tamil Nadu and Rajasthan.	Water related diseases	In-home treatment of drinking water using cloth filters, ceramic filters and boiling.	Based on framework where households produce health from expenditure on water quality, and derive utility from health as well as a composite good. The demand for any mode of in-home treatment is estimated using a linear probability model (LPM). Impact of source protection (improvement in source water quality) on in-home treatment (averting measure) is obtained using standard two stage least squares (2SLS).	Each mode of in-home treatment leads to reductions in coliform contamination. Expensive technologies such as boiling and chemical leads to larger reductions. The marginal effect of such treatment is greater for households with unimproved water supplies indicating substitutability. Hence, the per capita gain from source protection (0.5–1% of total expenditure) can be considered for representing the benefit from averting measures.
Martini and Tiezzi (2014)	Eight sub-regions representing four macro-regions of Italy: Northeast (NE), Northwest (NW), Centre (CE), South and the Islands (SI).	Air quality having health effects in terms of respiratory diseases	Expenditure on air conditioners	Theoretical model based on household production function which combine a market good (air conditioning) with a nonmarket good (the level of external air quality) to produce the desired level of internal air quality chosen by the households. A two-step estimator used which involves probit estimation in the first step and a selectivity-augmented equation system in the second step.	WTP is smaller than 10 euros for most households, with very high frequency of a value around 3 euros. Since the household production function implicitly describes the marginal rate of substitution between air quality and air conditioning, the computed marginal willingness to pay would represent the marginal improvements in air quality.
Aziz, et al. (2014)	Matlab area in south-eastern Bangladesh	Multiple health hazards from high levels of arsenic in drinking water particularly in children	Households decision to switch away from using water from red (having arsenic concentration higher than safe limits) tube wells to green (with below safer limits) tube wells.	Theoretical framework based on health production function. Discrete ordered probit has been used to estimate child health	Monetary benefits not estimated. However, improvement of child health was observed in households adopting averting measures.
Aziz et al. (2015)	Matlab area in south-eastern Bangladesh	Multiple health hazards from high levels of arsenic in drinking water particularly in children	Households decision to switch away from using water from red (having arsenic concentration higher than safe limits) tube wells to green (with below safer limits) tube wells.	Household production framework where a health production function that allows mutual influence of parent and child health status is estimated. Four simultaneous probit models were estimated using the Qualitative and Limited Dependent Variable Model (QLIM) procedure.	Improvement of child and parent health was observed in households which adopted averting measures. The monetary equivalent for the cost of averting measure (the time spent on fetching arsenic free water) has been estimated to be about 10% of their daily wage.
Bakhsh et al. (2016)	Vehari district of Pakistani Punjab, Pakistan	Health effects of pesticide exposure during cotton picking in women workers	Use of Gloves, Scarf/Handkerchief, Shoes, socks, etc. Delaying picking.	Health cost function similar to a utility maximizing or a health production function has been used. A log-linear model is estimated where health cost is modelled as function of socioeconomic characteristics, precautionary (averting) measures, type of cotton harvested and access to hospital	Health cost of the workers in the Bt cotton fields using precautionary measures was found to be less (US$ 2.84) compared to those using no precautionary measures (US$ 2.96).
Sayal et al. (2016)	Dingi Village near adjacent to an industrial estate in Haripur Pakistan	Impact of lead (Pb) contamination of drinking water from industrial effluents	Boiling water (most commonly used), chlorination, purchasing bottled water, and a filter cartridge.	Theoretical framework based on the health production function. A probit model has been used to estimate the probability of sickness and determine the medical and avertive costs.	Using probabilities of sickness, medical costs, and avertive costs the marginal WTP was estimated at $53 per household per year. The opportunity cost of avertive measures was estimated as $54.

(*continued on next page*)

Table 1 (*continued*)

Authors	Study Location	Health effects	Averting measures (coping measures)	Methodology	Benefits with averting (coping)/Adaptation measures.
Mokondoko et al. (2016)	Micro-watershed area of the upper Antigua River located in the central Veracruz state in Mexico	Cholera-induced diarrhea (Water related gastrointestinal diseases)	Public education campaigns for disease prevention	Health production function was estimated. The model combining the estimated public health costs with the observed relationship between primary forest and E. coli, along with an area factor was estimated using regression. The estimates were used to obtain per hectare marginal value of primary forest cover that helps in avoiding incidence of diarrheal diseases and mitigation and defensive (avertive) costs.	The average total cost of treatment and defensive (averting measure of public campaign) measure was estimated as $US4,455,644 dollars per year of which defensive cost was $US248,700 dollars per year. Benefits in term of savings in treatment cost was estimated as $US189,750 dollars per year from mitigating measure of conserving primary forest. The value of water quality regulation by primary forest was estimated to be $US90dollars ha^{-1} within riparian zones.
Deschênes et al. (2017)	19 Eastern states plus DC of USA	Health effects due to ozone pollution caused by emission of NOx.	Defensive investment in terms of medication expenditure – medication taken regularly to avoid appearance of symptoms has been considered as averting measure.	Becker-Grossman health production function approach. Differences-in-differences-in-differences (DDD) estimator was used to isolate the causal effects of the emissions market on pollution, defensive investments, and health, and use instrumental variables to measure the "structural" effect of NOx emissions and ozone on the same outcomes.	About 1.6 percent or around $800 million annual reduction in medication expenditures where the Nitrogen Oxides (NOx) Budget Program (NBP), a Cap-Trade market for NOx was in force. Also individuals' compensatory behavior and resulting defensive investments accounts for one-third of WTP for reduction in NOx emission.

Note: The search was carried out for journal articles published during the period 1985 – 2018. Review of the journal articles published during the recent period (2000–2018) only has been summarized in this table. Prior to these (1985–2000) only three studies (Bresnahan et al., 1997; Gerking & Stanley, 1986; Joyce et al., 1989) matched the selection criteria and all them dealt with health benefit of averting measures for reduction in health damage due to air pollution.

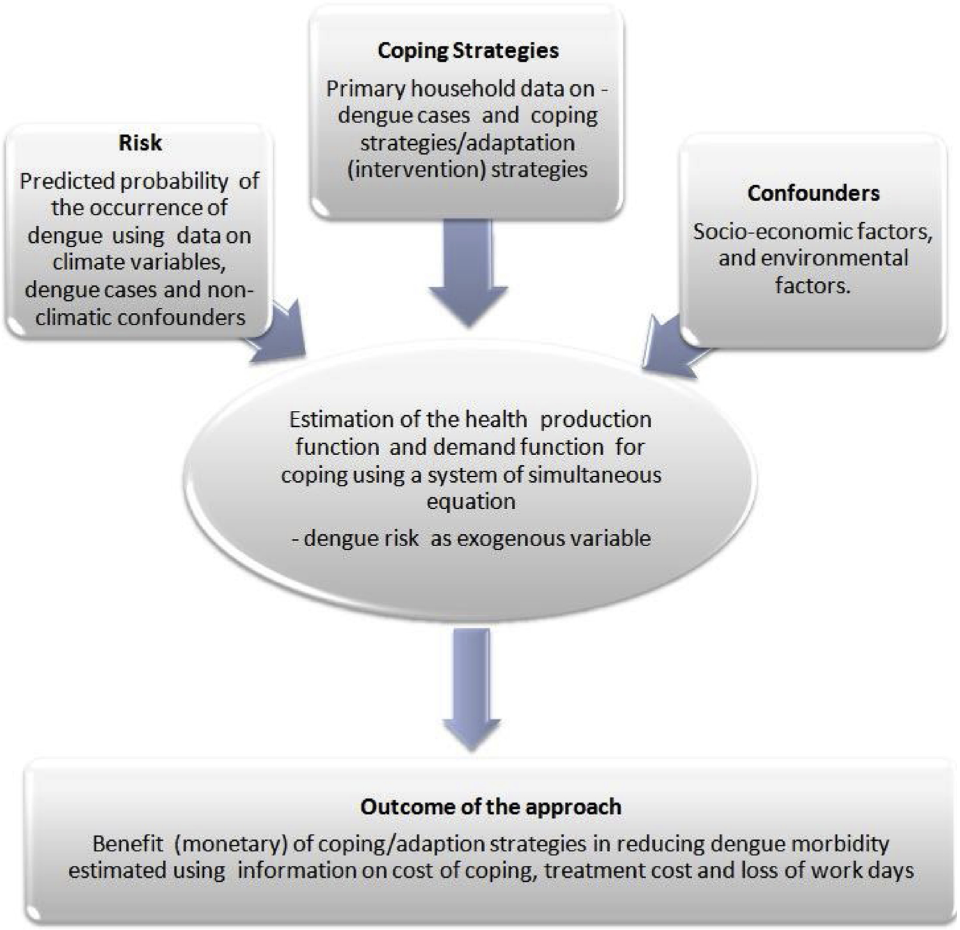

Fig. 2. Empirical evaluation framework for coping strategies using Health Production Function (HPF) approach.

on effectiveness of the coping strategies in reducing morbidity and economic benefit derived by the residents by adopting coping strategies (see Table 1 for the benefits of averting (coping)/adaptation measures estimated using HPF approach in different studies). The information serves as a measure of coping capacity of the residents and is crucial for planning adaptation to develop resilience and build adaptive capacity. The HPF implicitly measures the effectiveness and adequacy of the adaptation measures planned and implemented by the local government. Reduction in the coping cost by the households combined with decrease in disease incidence over a period of time provides evidence for the effectiveness of adaptation measures.

The health production function based model used for evaluating the coping strategies follows the model given in Deschenes and Greenstone (2011); Graff Zivin and Neidell (2013) and Deschenes (2014). It assumes that the climate variability and change leading to disease incidence influences the utility derived by the households from consuming marketed goods and services and state of health. The production function for time spent ill (S) is expressed as $S = S\,(X_H, C)$, where S depends on the coping strategies (X_H) and the disease risk associated with the weather patterns (C). The coping strategies (X_H) is adopted to decrease the health risk and includes strategies such as measures to prevent mosquito bites and breeding for dengue; use of air conditioner and staying indoor for heat related health outcomes; and water purification measures for water-borne diseases. For details of the model see Sahay (2018a).

The marginal willingness to pay (MWP) is determined by estimating a system of simultaneous equations for the health production function and the demand function for coping strategies (X_H) after taking into consideration appropriate confounders such as socio-economic factors, environmental factors and intervention measures or the adaptation measures implemented by the local government. The marginal effect of the coping strategies (X_H) obtained from the estimation is used to calculate the MWP for reduction in illness time or benefits of coping. The approach has been validated for Delhi, India, a city with high dengue endemicity by Sahay (2018a) (see supplementary material 2 for the econometric model estimated). The estimated benefit implicitly includes the effect of the cost incurred by the local government through inclusion of intervention measures in the model as predictor. Thus, estimation of the model provides following crucial information for the decision makers: benefits of adopting coping strategies after considering socio-economic and other confounding factors; cost of adopting these strategies; effectiveness of coping strategies; and most importantly it measures the effectiveness of intervention measures practised by the local government. In case adaptation measures have already been implemented, the reduction in coping cost along with disease incidence over a period of time can be attributed to the effectiveness of the planned adaptation measures.

The HPF approach proves to be an efficient tool as it contributes to planning of adaptation measure along with monitoring and evaluation of adaptation measures which are already in practise. It serves as bottom-up approach for evaluation of urban adaptation to health effects of climate change. However, the approach uses the existing health risk due to changes in weather patterns as exogenous input in the model and it does not facilitate use of projected risk for future period. This limits the use of HPF approach to any given point of time only. Thus, there is a need for this approach to be dynamic to accommodate future dengue risk and changes in the effectiveness of adaptation strategies. This is achieved by applying it at regular interval.

3.2. Framework using HPF approach as decision support tool for health adaptation

The empirical framework using HPF approach can be very effective decision tool for adaptation assessment for future health risk at the city level. There is however, a growing concern for addressing and incorporating uncertainty in adaptation assessment (Watkiss et al., 2015). Uncertainty is associated with future projection of health risk due to uncertainty in future projection of climatic as well as non-climatic factors. In the wake of challenges faced in projection of future health risk, adaptation planning at the city level becomes very difficult. Also, the adaptation strategies cannot be decided by the policy makers at any single given point of time, rather it has to be an ongoing process of assessment and evaluation for their effectiveness. The HPF approach uses the current risk as exogenous input in the model, hence the associated uncertainty do not gets integrated in the evaluation model of the proposed framework.

Presently, designing and implementation of interventions using projected health impacts under different climate and socio-economic future to serve as early warning system or make adjustments in current interventions is lacking and needs further research (Ebi, 2018). In case of dengue, recently, efforts have been made to come up with more accurate methodologies for projections of dengue incidence at the city level. In one such effort, the long term projection of the dengue incidence under the latest climate scenarios of RCP2.6 and RCP8.5 has been carried out at the city level by Li et al. (2017). Early warning framework has been developed for predicting dengue risk at the start of a year (Lowe et al., 2016, 2017). These predictions are based only on the projected values for the climate variables, while completely ignoring the expected changes in the socio-economic conditions of the area during the projected period. It is difficult to assume that the socio-economic conditions and effectiveness of interventions would remain same throughout the projection period. The predictions based only on projected climate variables under different RCPs or the early warning systems, therefore, may not contribute adequately to adaptation planning. Further downscaling of the global socio-economic scenarios developed as the Shared Socio-economic Pathways (SSPs) (Moss et al., 2010; O'Neill et al., 2017) at the local level as extended SSPs is still in a very nascent stage with no quantitative projections available (Nilsson et al., 2017).

To avoid uncertainty arising from the disease projection and subsequent adaptation in its response, a dynamic approach in the form of a cyclical framework for decision making is proposed (Fig. 3). The HPF approach serves as a decision tool in the framework which uses the current dengue risk, socio-economic conditions, coping strategies and the intervention measures in practise. The framework addresses uncertainty by eliminating the need for future projection for dengue risk, climatic and non-climatic factors as the cyclical framework can be applied at any point of time in future.

The timing of application of the cyclical framework is fixed at an interval of five years or it may be even earlier depending on the results of regular monitoring of the disease occurrence (Fig. 3). Cities across the globe and in developing countries, in particular, are highly dynamic in terms of changes in settlement patterns, demographic, socio-economic and environmental conditions. An interval of five years is suggested as the period can be considered as sufficiently long enough for measurable changes in these parameters. A five yearly assessment of the effectiveness and adequacy of the adaptation measures is also in line with the stocktaking requirements of the Article 7, paragraph 14 of the Paris Agreement (Craft & Fisher, 2018; Tompkins et al., 2018). Initiating the evaluation cycle at fixed intervals helps in overcoming the risk of the tool being reactive. The timely assessment and the subsequent changes in the adaptation measures enhance the adaptive capacity and contribute proactively in reducing the future health risks.

The cyclical framework involves a five step evaluation process. In the first step (Step – I) an assessment of the current status of the dengue occurrence in the city along with the adaptation strategies or intervention measures which is being practised is carried out. The outcome of the assessment serves to take decision on the need for evaluation of the adaptation strategies. For example, the information on dengue cases availed through sentinel surveillance each year would help the local government to monitor the intensity of the disease and help to decide on the timing for initiating the evaluation cycle. It can be initiated if there is a marked increase in cases in successive years even before the fixed interval of five years.

Once the decision is made on evaluation, the next step (Step – II) involves determining the risk of dengue due to weather patterns. This is achieved empirically using the data on climate variables and cases. The high risk weeks identified as in case of Delhi helps determining the current risk period of a year and also identifies any change in risk as compared to previous evaluation cycle (Sahay, 2018a). This is very crucial in making adjustments in timing of the intervention measures. Such information enhances the role of climate services in adaptation planning for health sector. The risk determined in this step serves as exogenous input in the HPF approach for evaluation of coping and adaptation strategies in practise.

The HPF approach is essentially a bottom-up approach and requires household data for economic evaluation of adaptation strategies. The third step (Step – III) mainly involves collection of data at the household level on disease occurrence, the coping strategies adopted by the households in response to the disease risk, the interventions measures by the local government, demographic details, socio-economic status and surrounding environment. For example, Sahay (2018a) finds that in Delhi, use of mosquito repellent throughout day and night as the most effective coping strategies. Intervention measures by the local government included thermal fogging and checking households for the presence of vector breeding sites. The outcome of this step helps in understanding the adjustments and improvements made in the intervention measures as compared to the previous cycle. This includes change in timing or reach of interventions to the most vulnerable section of the city.

Both, the risk determined in step-II and household data collected in step-III are used in step- IV which uses the HPF approach for evaluation of the coping and adaptation strategies. In this framework, the HPF approach is the decision tool as it provides empirical evidence on the effectiveness of the adaptation measures in practise, economic benefits and cost of coping strategies for the risk and the gaps in adaptation planning. The outcome helps policy maker to make an assessment of the adaptation deficit as compared the previous cycle. Based on the outcome of the evaluation, in step – V, the policy maker takes the decision on planning of adaptation strategies for the disease risk. The planning includes adjustments in the existing adaptation as well as implementation of new adaptation strategies.

As in case of Delhi, where interventions are already being practised, Sahay (2018a) finds that the results of the HPF approach provide vital information for the policy makers such as inappropriate timing of the interventions as the reasons for ineffectiveness of the intervention measures; low-income households as the vulnerable population of the city; lack of basic amenities like irregular water supply contributing to the disease risk; annual cost of US$ 17 per household for adopting coping strategies; and annual benefits of US$ 65 that a household derives by adopting coping strategies.

Once the adaptation strategies have been planned and implemented, the next step is to monitor the effectiveness of adaptation in reducing the morbidity. This is achieved by regular monitoring of the disease occurrence. Such regular monitoring will help to decide the timing of initiating the evaluation cycle again with step – I, if needed, before the recommended time interval of five years between two successive evaluation cycles. Decrease in cost of coping by the households combined with reduction in disease occurrence in the subsequent evaluation cycle is the most prominent indicator of the effectiveness of the adaptation strategies implemented by the local government.

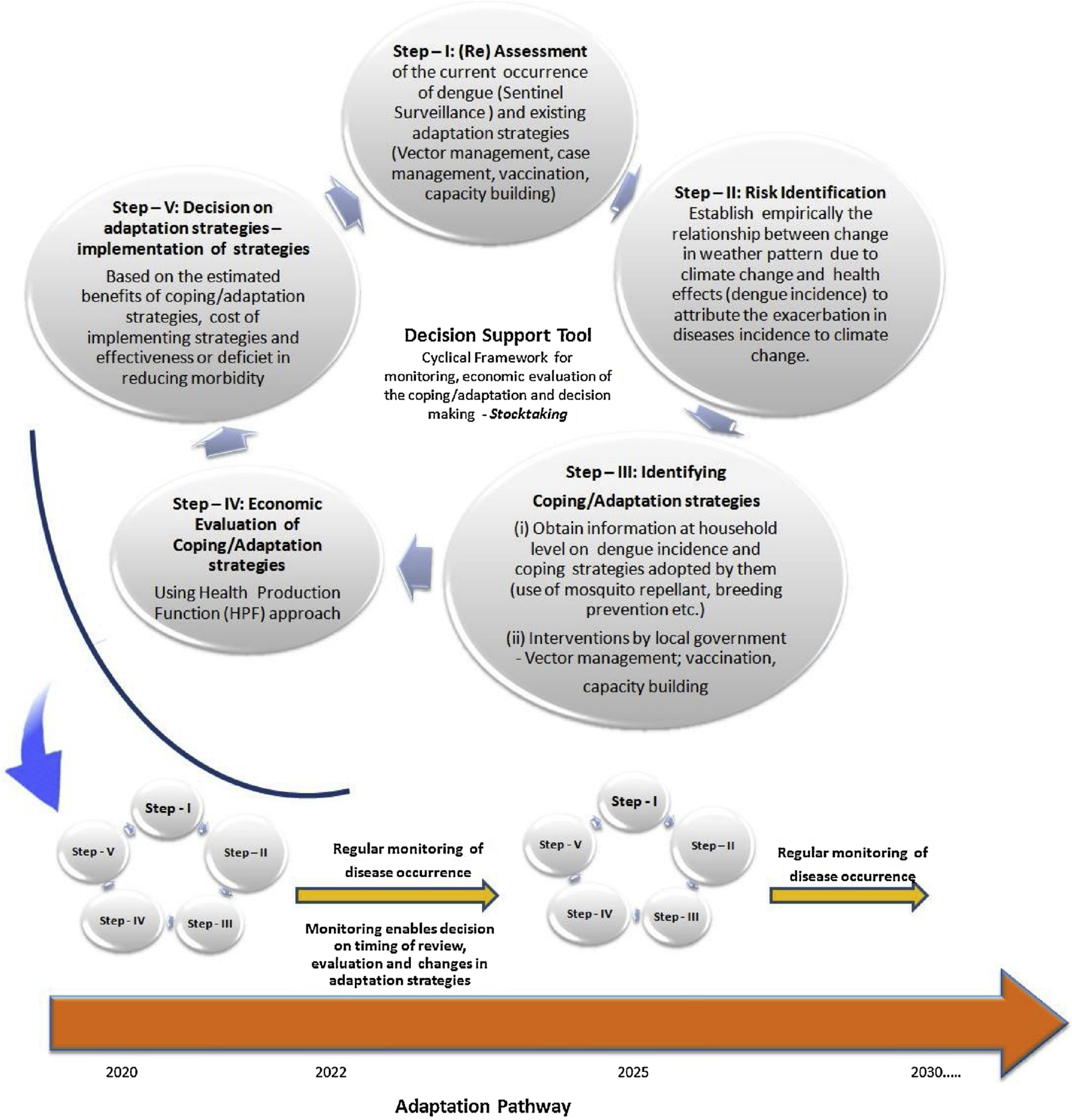

Fig. 3. Empirical Decision Support Tool for Health Adaptation – Cyclical framework for monitoring, economic evaluation of the coping/adaptation and decision making at any given time. The framework follows 'adaptation pathway' approach. The cyclical framework can be applied at any point of time in future. A fixed interval of five year is recommended between two successive evaluation cycles. This eliminates the need for scenario building and future projection of disease incidence.

4. Discussion

The proposed cyclical framework follows the 'adaptation pathways' approach for decision making for health risks (Fig. 3). The framework draws similarities with iterative risk management (IRM) framework which considers uncertainty and involves iterative cycle of monitor, evaluation and learns (Ebi & del Barrio, 2017; Ebi, 2018; Lavell et al., 2012; Watkiss et al., 2015; Wise et al., 2014). The IRM framework is based on the principle of adjusting decision on adaptation over time, backed by evidence rather than taking irreversible decision at present which might not be even needed in future (Reeder & Ranger, 2011). The evaluation of adaptation strategies in IRM is carried out using the conventional tools of CBA, CEA and multi-criteria analysis (MCA). The economic evaluation of adaptation is not very common in IRM as methodology for such evaluation to date remains underdeveloped (Watkiss et al., 2015).

However, the framework proposed in this study differs from IRM as HPF approach allows for economic evaluation of the coping and adaptation at any given time. Unlike traditional decision tools of CBA and CEA, the approach takes into account both market as well as non-market cost and also considers socio-economic factors. The approach does not facilitate integration of uncertainty in the framework for decision making. It addresses the uncertainty arising out of future projections for disease risk, climate variables and socio-economic factors at the city level by avoiding the need for use of any such projections. This is achieved as the framework is applicable at any given time in future which keeps policy makers informed about the existing effectiveness of the adaptation and the need for any updating required at that point of

Table 2
Decision support framework for Health Adaptation (under uncertainty).

	Iterative Risk Management*	Decision tool using Health Production Function (HPF) Approach	Robust decision Making* (RDM)
Approach	Iterative process of monitoring, research, evaluation and learning (cycle) to improve future management strategies.	Involves a cycle of assessment of current disease (dengue) risk, coping/adaptation strategies by private actors and local government, economic evaluation of strategies and decision on adaptation strategies at any given time. Outcome is used for taking decision to update existing strategies.	Preparing structure of the problem, proposing alternative strategies and identifying performance measures. Uncertainty parameters or range of potential values is assigned to key variables to determine the levels of uncertainty associated with these strategies and performance measures.
Key features	Can be linked to on-going monitoring and a cycle of review, which enables learning and revision of the strategy over time.	Allows economic evaluation of coping/adaptation strategies at any point of time in the pathway based on the current risk at that time. The evaluation cycle can be applied at intervals enabling a continuous monitoring – Duration of the interval to be based on regular monitoring of trend and spatial distribution of disease incidence (sentinel surveillance). This reduces the need to construct future risk scenarios to treat uncertainty which is very difficult for health effects particularly dengue as future projection is very uncertain. The framework eliminates the need to determine the risk threshold (following which decision cycle needs to be reconsidered).	Focus is on robustness rather than economic optimisation. It is used for testing strategies across a large number of future possibilities and is used for decision making under deep uncertainty where very little or no information is available about future risk.
Key inputs	Requires constructing sets of scenario and several sets of outputs of climate model along with determining threshold levels for risks (level of vulnerability/impact that could trigger risk).	Existing disease risk and information on coping/ adaptation is required. Scenario creation not recommended. Hence, determining of threshold not required.	Requires constructing multi-model scenario and outputs of climate model along with information on uncertainty for all parameters.
Evaluation tool for decision making	Decision tools of CBA, CEA and MCA can be applied for evaluation. Benefits expressed in quantitative or economic terms.	Health Production function (HPF) approach used for evaluation. Benefits expressed in quantitative and economic terms.	Computer model analyses strategies using a data sampling algorithm which uses thousands or millions of runs representing different possible future conditions. Summary of key trade-offs across the most robust strategies is prepared after incorporating the uncertainties which allows assigning weights to trade-offs for selection. Benefits expressed in quantitative and economic terms.
Major advantages	Allows for taking decision adjusted over time with evidence now and eliminates the need for taking irreversible decision now which may not be even needed in future.	Allows for taking decision now, monitor the results of implementation of adaptation after some time and accordingly update the strategies. Not very data intensive (socio-economic data of residents and environmental data required) Does not require heavy computation. Eliminates the need for making future projections of disease (dengue), thus addresses the major concern of uncertainty in evaluation. Allows evaluation of both technical and non-technical options.	Very useful tool for taking decision now in case where future uncertainties or probabilistic information is very limited or unavailable. A very high preference is given to importance of relative uncertainties in the model inputs. Suitable for comparing technical and non-technical sets of options.
Shortcomings	Difficult to identify the risk thresholds, particularly when multiple impact risk acting together limiting its application to impacts such as sea level rise which is gradual and in one direction. Thus far it has not been applied in health sector and threshold identification may serve as major limitation.	As determining of threshold is not required, it has to be applied more often. Requires data at household level which restricts it suitability to smaller geographical areas like cities. Aggregating or up scaling results to larger geographical areas may not be feasible.	In the absence of quantitative probabilities it can be more subjective and easily get influenced by perception of stakeholders. It is highly data intensive and requires very high computational power and expert resources.
Potential uses of approach and limitations	Most useful for assessment over medium-longer term with clear risk thresholds. Applicable as a framework at policy level. Suitable in cases with mix of quantitative and qualitative information and non-monetary areas such as ecosystems and health.	Framework for health adaptation policy development relevant for short-medium term having potential to evaluate and update at intervals in future. Applicable for all climate-sensitive health effects – vector-borne, water-borne and heat related. Mix of quantitative and qualitative information. Applied at household/community/individual level and also policy level for adaptation strategies for review. Approach is applicable exclusively for health sector.	Identifying low- and no-regret options and robust decisions for investments with long life-times. Testing near – term options or strategies across number of futures or projections (robustness). Comparing technical and non-technical sets of options. Suitable in cases with mix of quantitative and qualitative information and non-monetary areas such as ecosystems and health.

* Adapted from Watkiss et al. (2015). CBA – Cost-benefit Analysis; CEA – Cost-effectiveness Analysis; MCA – Multi-criteria Analysis.

time. It provides the measure of existing coping capacity at the given time and also the level of adaptive capacity generated as compared to the previous cycle of evaluation. Such timely information helps policy makers to accordingly update the adaptation strategies already in practise, take decision on the effective set of initiatives as adaptation strategies and eliminate the risk of incorrect resource allocation, making the city more resilient to the risk. It serves as an efficient stocktaking tool.

The framework eliminates the need for determining threshold risk as required in IRM. It does not take in to account future risk scenarios and recommends review based on the current risk at any given time in future. It is neither data intensive nor involves computational complexity as in case of robust decision making (RDM); another effective tool for economic decision making under uncertainty. Conducting household surveys to collect data, specifically on coping strategies at regular intervals might be expensive at the local level in low income countries. To avoid additional financial burden, data can be collected along with regular surveys carried out in most of the countries to collect data on socio-economic indicators like consumption expenditure, family health status and living standard indicators. Comparative analysis of the proposed framework with HPF approach, IRM and RDM which can be used for health adaptation assessment is provided in Table 2.

The HPF approach serves as an empirical decision tool for adaptation strategies for health risk at the city level. The empirical model facilitates economic assessment of the adaptation strategies such as vaccination programmes, vector management programme, preparedness of health care services and even non-technical strategies such as capacity building, awareness programmes and monitoring and evaluation programmes. The HPF approach uses household data at the city level. Hence, it serves as a bottom-up approach for policy assessment. The model allows use of the variables representing coping strategies such as mosquito repellents for dengue, air conditioners for heat related health effects and water purification techniques for water-borne diseases as X_H in the health production model for residents. This enables estimation of their benefits in monetary terms and effectiveness of the adaptation strategies in terms of reduction in morbidity.

5. Conclusion

The need and importance of adaptation at the city level is now well recognized. With adaptation to health risk mostly confined to cities in developed economies, contribution of coping strategies with short-term benefits, adopted by residents to address health risk in cities of developing economies becomes crucial for planning adaptation strategies for future risk. Therefore, economic assessment of the coping strategies serves as an important tool for informing policy makers about the benefits and effectiveness of coping and determining the shortcoming in adaptation strategies implemented by the local government.

The present paper is an effort to come up with an empirical decision support tool for adaptation planner, specifically for climate-sensitive health outcomes at the city level. Based on the review of empirical studies evaluating benefits of averting actions to reduce the health effects of environmental pollutants, the study finds that the HPF approach can be very effective in empirical evaluation of coping or adaptation strategies for climate-sensitive health outcomes at the city level. To address the concern about incorporating uncertainty in decision support tool, the paper proposes a cyclical framework using HPF approach as a decision tool. In the absence of projected health outcomes under different climate and socio-economic future at local level, the proposed five step framework addresses the uncertainty by eliminating the need for such projections. It can be applied at any point of time in future and it uses the then current disease risk due to weather patterns. The risk of the tool being reactive is taken care of by applying it at fixed interval of five years. Also, it is computationally less complex. The framework is most suitable and effective decision support tool for adaptation at the city level and can be applied to all climate-sensitive health outcomes.

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Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2019.101512.

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